

ASTRONAUT TOOL DEVELOPMENT:  
AN ORBITAL REPLACEABLE UNIT-PORTABLE HANDHOLD

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ABSTRACT

This paper describes the design and development of a tool to be used during astronaut Extra-Vehicular Activity (EVA) replacement of spent or defective electrical/electronic component boxes (herein referred to as Orbital Replaceable Units or ORUs). The generation of requirements and design philosophies are detailed, as well as specifics relating to mechanical development, interface verifications, testing, and astronaut feedback. Findings are presented in the form of: (1) a design which is universally applicable to spacecraft component replacement and (2) guidelines that the vehicle-side designer of ORUs might incorporate to enhance spacecraft on-orbit maintainability and EVA mission safety.

INTRODUCTION

Earth-orbiting spacecraft destined for long-term use must frequently be designed for "orbital maintenance." Examples of such are the Hubble Space Telescope (HST), Space Station, AXAF, etc. On such a vehicle, the replacement of various "black boxes" such as data units, recorders, and batteries is due long before the useful life of the core vehicle is expended. Knowing this, the vehicle design groups can incorporate features which will facilitate on-orbit maintenance, e.g., quick-acting fasteners, dowels/guides, special fluid/electrical connections, handles, etc. Sometimes, however, these niceties cannot be successfully integrated. These instances include:

- Existing Spacecraft (HST)
- Unforecast Replacement (HST)
- Volume/Weight Constraints.

When these, or other, circumstances prevail, alternative schemes surface and are analyzed in regard to astronaut safety, EVA performance timelines, component downtime, etc. In the category of "handling," a convenient means must be provided for the astronaut to transport and articulate the "boxes" into and out of position, typically at an arms length, in tight quarters, combating the effects of fatigue and discomfort, and under poor lighting conditions. As a result, the need for a portable, universally applicable, latch-on type handle, or handhold, was precipitated. Requirements for such a device, as it pertains to the HST, are as follows:

- Box size .....5 to 30 in.
- Box Design/Interface.....Flange Top/Smooth Top/Ribbed  
(20 various designs/shapes)

Due to the quantity of boxes, the variety of sizes/designs, and the likelihood that more boxes could be added to the list at a later date, several design philosophies were incorporated early on:

- "Infinitely" adjustable clamp
- High degree of modularity/design flexibility
- Telescoping - No extensions to assemble while on-orbit
- Soft latch-elastomeric latch pads.

The design that followed may be described as a hand-actuated, double-telescoping, linear-clamping device with a ratchetted rack/pinion locking drive (see Figures 1 through 5). High linear resolution would be provided by a 120-tooth sawtooth ratchet which translates to 0.017 in. of spur gear pitch line movement; variability between ratchet teeth would be provided by compliance of the rubber pads.

#### DESIGN-ASTRONAUT INTERFACE

During the course of design, much contemplation was given to the amount of hand-cranked torque to be applied and the resulting linear clamping force exerted on the ORU. As a general guide, 40 to 50 in.-lbs was used as the input torque provided by an astronaut's gloved hand using "wrist action" motions. The required linear clamping load to effect a good latch, however, depends on the box surface area exposed to the latch pads, and temperature (due to the compliance of rubber and its frictional properties). Obviously, not enough load would result in a poor grip while, on the other hand, too much load could possibly damage the ORU. Due to this relatively wide variation in required load, torque limiting, or "clutching," was discounted as a means to assure grip integrity. Instead, it was decided to design the device with a high degree of "feel" or tactile behavior. This is accomplished by selecting a gear ratio, handle length, and compliance value comensurate with adequate linear loads, reasonable astronaut input torque values, and a rapidly increasing resistance to input torque, as the target clamp load is approached (i.e., feel).

#### DESIGN-MECHANICAL CONSIDERATIONS

The need for operational simplicity, tactile behavior, compactness, extremely fine linear adjustability, and ruggedness precipitated some rather interesting concerns in the mechanical packaging. With the small size, loads on the intricate gears and tiny shafts, as well as gear fastening problems, soon became apparent. Similarly, the need for smooth, frictionless operation under load and in the absence of lubrication surfaced. The challenge soon became how to package the drive gearing, ratchet gearing, crank handle, ratchet release, and pawl, locating each of the three shafts on miniature deep groove ball bearings. To accomplish this, several unconventional means were utilized.

Examples of these are: The use of large ball bearing/ small bearings on a common stepped shaft in order to facilitate assembly and provide a large

shaft diameter where more material was needed for strength and/or fastening interface; secondly, utilization of gear mesh interference to provide rotational constraint of the telescoping rods; and lastly, the use of an "overhung" or cantilevered rack gear in order to provide more extension length. All of these methods worked out very well and proved not to contribute to friction, play, or excessive deflections, despite the fact that these methods seemed somewhat "unorthodox."

Fastening concerns were found in two areas: (1) attachment of the gears, pawl, and cam to their respective shafts, and (2) attachment of the elastomeric latch pads to their aluminum backing plates. The fastening of gears to shafts was critical because of the very small moment arms (0.063 in.) and shear areas on the gear/shaft interface. Integral shaft/gear arrangements were discounted because of expense, tooling complexity, and loss of modularity. It was therefore decided to interference fit the gears on the shaft and fusion weld the assembly using the highly weldable, nickel-based "super alloy" Inconel 718 on the gears and shaft. Because of the interference fit, a high degree of fusion occurred thus resulting in superb strength; no warpage problems occurred.

In fastening the elastomeric latch pads, several means were considered: adhesive bonding, through molding, and mechanical fastening. Bonding and through molding were discounted because of poor strength and complexity. As a consequence, a rather effective rubber/metal fastening technique was developed. The method consists of riveting the rubber to the aluminum with special load distributing washers and standoffs so that the rivet does not squeeze the rubber, no more than 10 percent. The technique provides a tenacious hold on the rubber while proving to be simple to implement, and easily removed.

Some consideration was given as to what type of linear bearing should be employed on the telescoping rods. Since the rods are exposed to the astronauts' touch, no lubrication could be used. Several engineering polymers were considered but were discounted due to flow properties and the potential for excessive deflection to cause adverse gear loading (lack of engagement). A ball bushing would suit the need for low friction under load, however, these types of linear bearings have a large envelope. As a result, it was decided to utilize a "hard" bushing and design a "materials couple" which would foster low friction and abrasive wear resistance. For this, a Nitronic 60/CRES 304 couple was selected along with honed/polished surfaces to 16 RMS, generous entry blending and a 0.001/0.002 in. diametrical clearance. The arrangement has worked very well; there have been no indications of wear, scratching, galling, etc., and the surfaces appear new even after months of testing in "unclean" environments.

#### TESTING/VERIFICATION

Testing of the device occurred, in one way or the other, every day after the first prototypes were build. Formal testing included: (1) fit verifications on vehicle, (2) instrumented ORU box deflection tests, (3) manned

thermal/vacuum tests for environmental suitability, (4) overload tests, and (5) underwater neutral buoyancy tests. During the course of these tests, much valuable information regarding the usage of the device was generated, and feedback from the astronauts proved enlightening as to the mental and physical aspects of EVA spacecraft repair. In general, formal testing went exceptionally well; minor "tailoring" modifications were made to the rubber latch pads for enhanced grip, the crank handle swivel joint was beefed up due to its propensity to bend and gall, directional arrows and instructional nomenclature was added to the housing, and teflon friction washers were added to reduce swivel handle "floppiness." In no cases were there any failures which prevented operation of the device. Further, overloads ten times that anticipated produced only minor deflections in the rods; no sheared fasteners or welds occurred and none of the tiny 32-pitch gear teeth were deformed.

Informal testing, although not as well documented, was probably as useful as any formal testing. This kind of testing includes the numerous cycles and operational permutations that the device undergoes between formal tests, typically by individuals unaccustomed to the device. Three types of data are available from this: (1) acclimation data, the adaptation of an individual to the operational characteristics; (2) improper operation data, i.e., can the device be misused?; and (3) the numerous cycles the device undergoes under the above mentioned conditions. To conduct these tests it is only necessary to leave the tool on your desk for a few months and observe a wide variety of people attempt to use it without instructions. No failures occurred during this "phase" of testing and it was observed that the device is very "user friendly." Directional arrows and instructional information engraved on the housing proved helpful for communication references, quicker adaptation, and possible "panic" situations.

Destructive tests are planned but have not been accomplished at the time of this writing due to Neutral Buoyancy test schedules. Figures 6 through 8 depict tests and verification activity.

#### SUMMARY

Thus far, development has gone exceptionally well and mission confidence surrounding use of the device is growing as more test time and neutral buoyancy usage is accumulated. I would, however, like to bring out several considerations that EVA tool designers and/or vehicle designers might consider for future work as it pertains to orbital maintenance, and specifically, component replacement.

- If weight or volume constraints prevent incorporation of "built-on" handles and tethers, vehicle designers should consider a suitable interface for handling means. A flanged box, as shown in Figure 5, is one of the more suitable configurations. The flange should be sufficiently rigid to withstand clamping loads. Notches, recesses, and/or clamp position placards, indicating a preferred clamp orientation, would also be desirable.

- EVA tools/mechanisms should be designed for 1-g underwater operation. Frequently viscous drag prevents delicate spring-loaded mechanisms from functioning properly underwater.
- Provide "fit-check" models early on. Frequently drawing data does not accurately reflect conditions on the vehicle, due to cabling, insulation, etc.
- Slots, guides, dowels, and visual aids should be incorporated for ease of installation.
- Winged connectors, captive fasteners, and large backshells suitable for gloved-hand operation are desirable.
- Good line-of-sight and accessibility are important. ORU designers might consider "canted" connectors or use of oblique surfaces to enhance visibility/accessibility.
- Parking and stowage should also be considered. Considerable EVA time can be saved by incorporating "snap-action" latches, ball-lock pins, etc., to circumvent attachment of threaded fasteners on stowage pallets.
- Further EVA information can be attained from: NASA-STD-3000, MSFC-STD-512A, and JSC-20466.

#### ACKNOWLEDGMENTS

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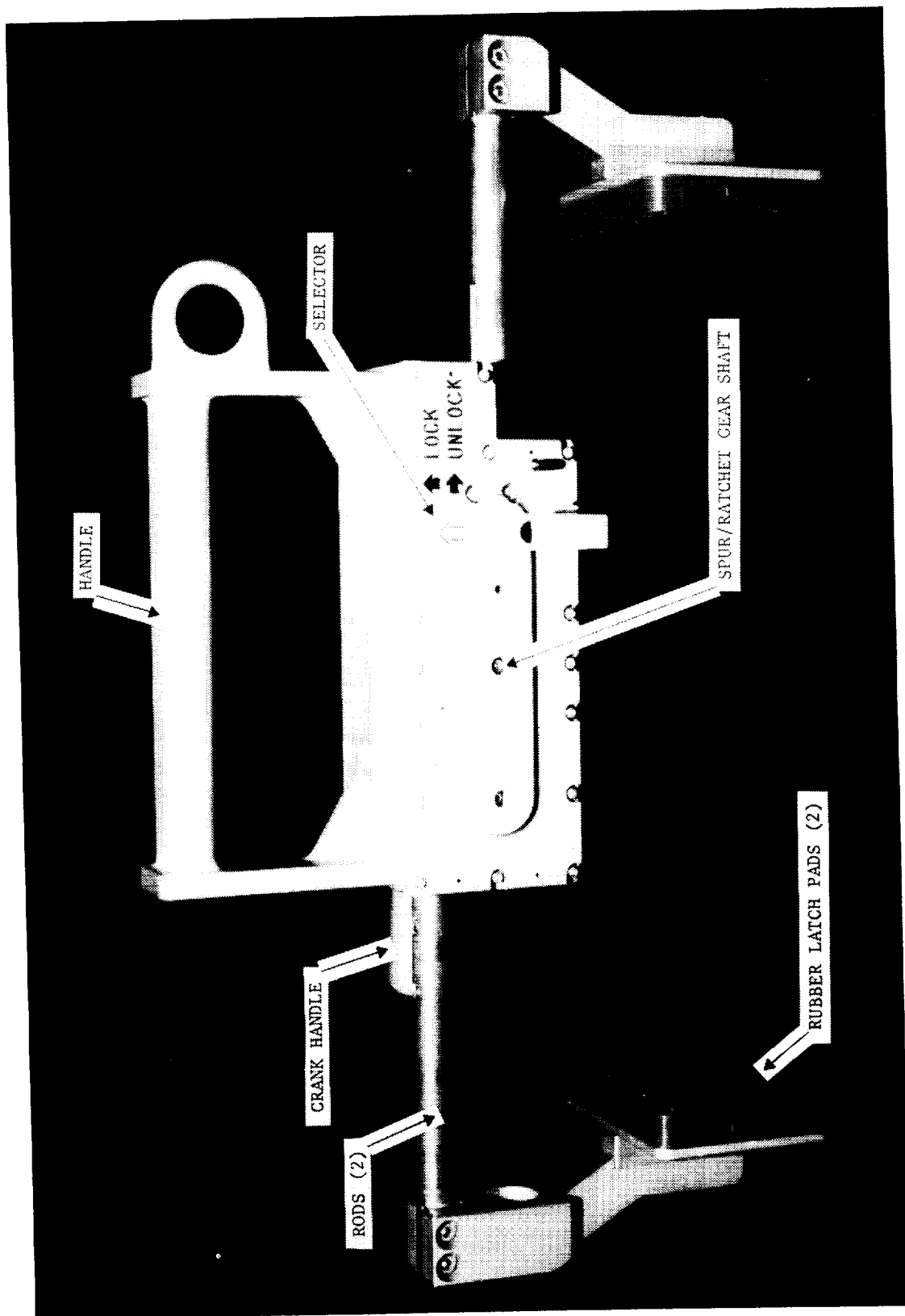


Figure 1. Portable Handhold (extended)

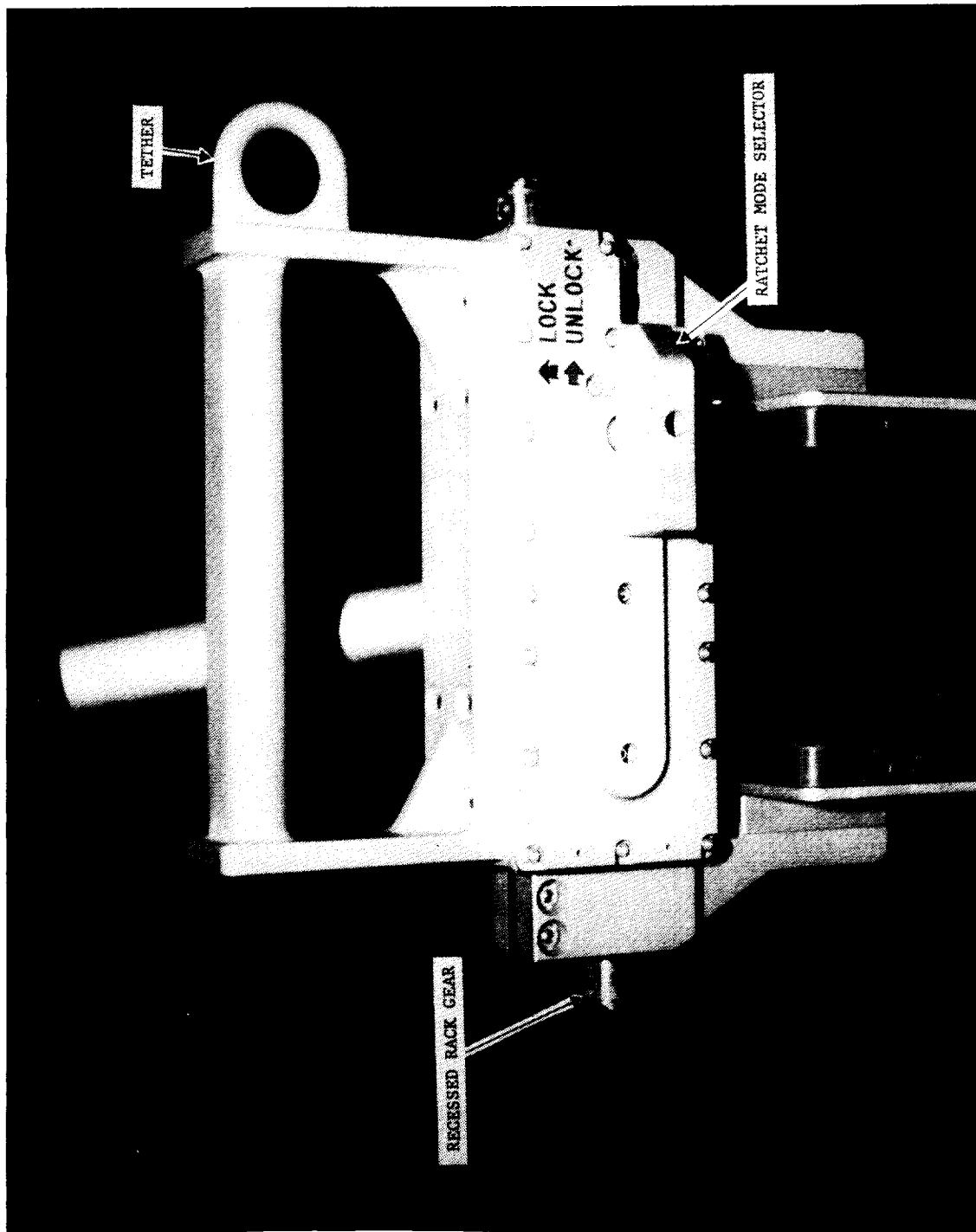


Figure 2. Portable Handhold (retracted)

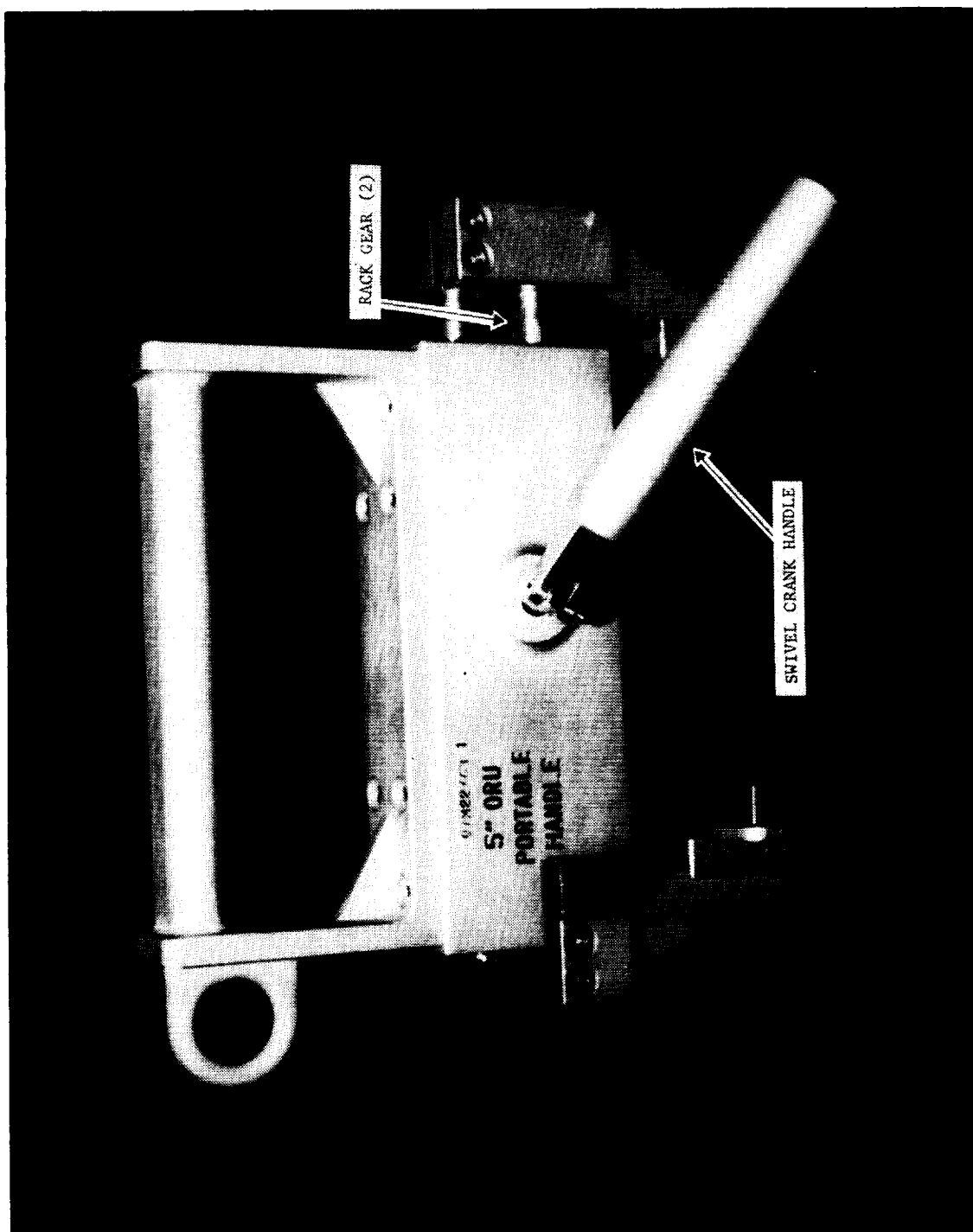


Figure 3. Portable Handhold

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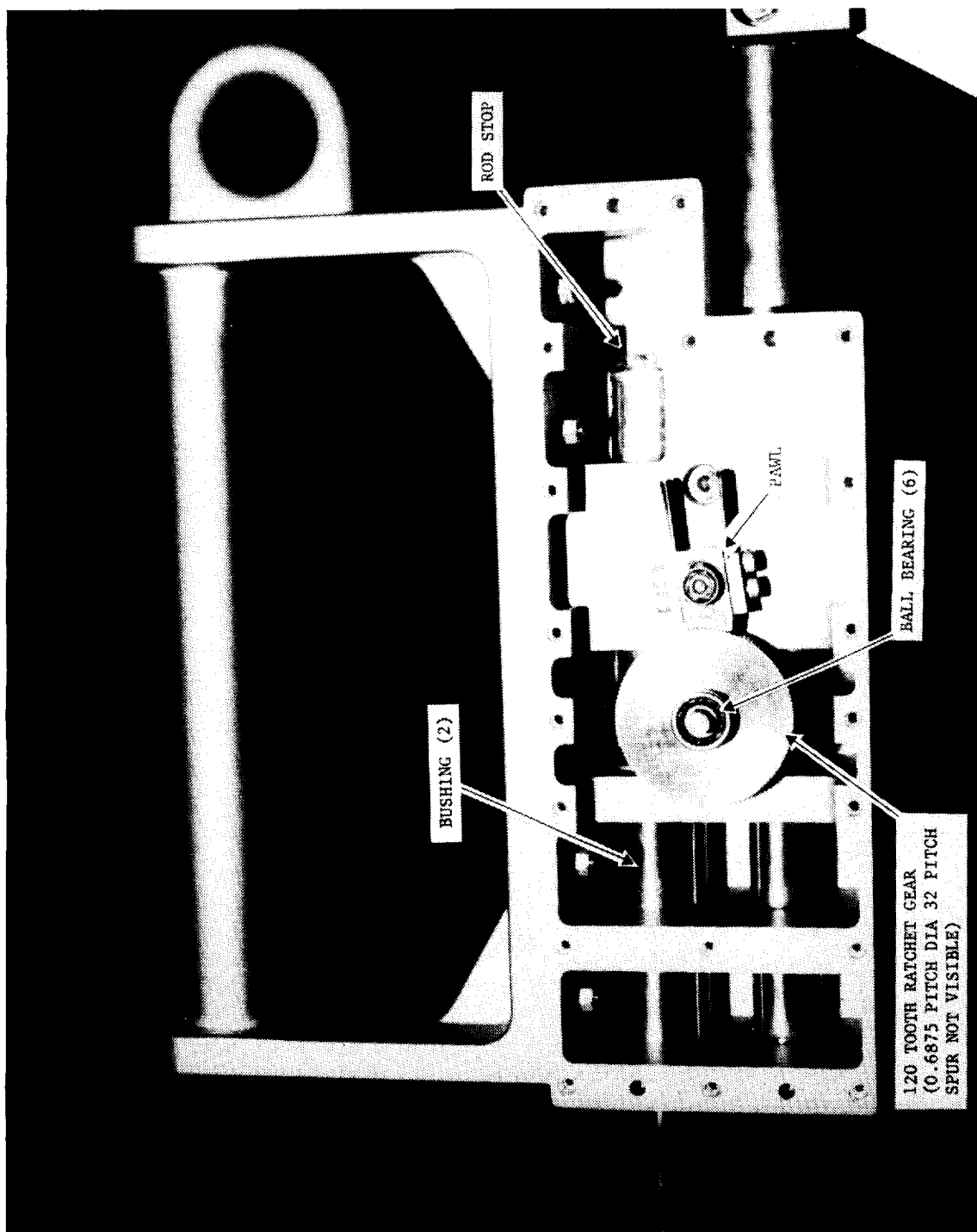


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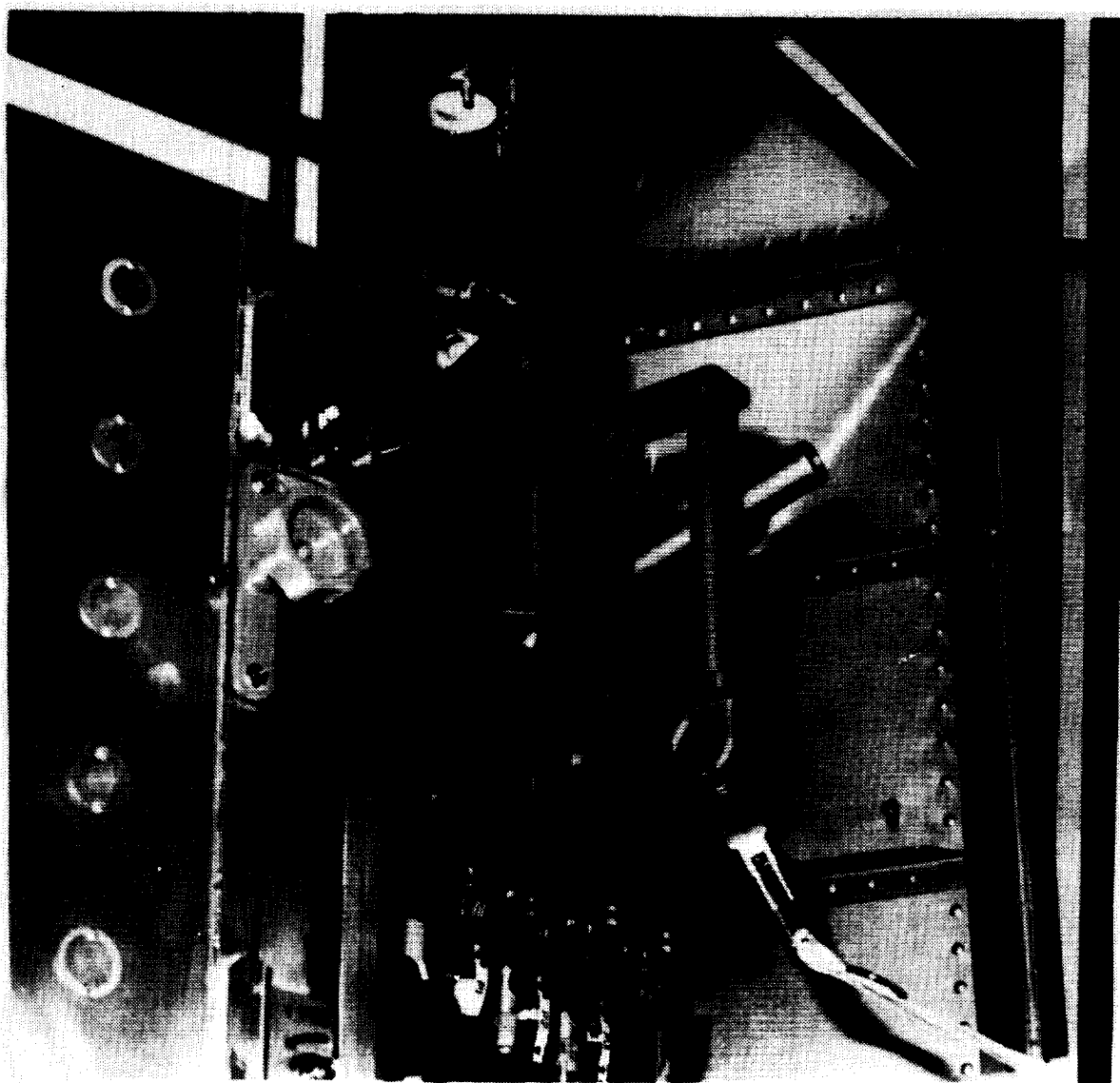


Figure 7. Later fit checks with flight fidelity unit verified latch

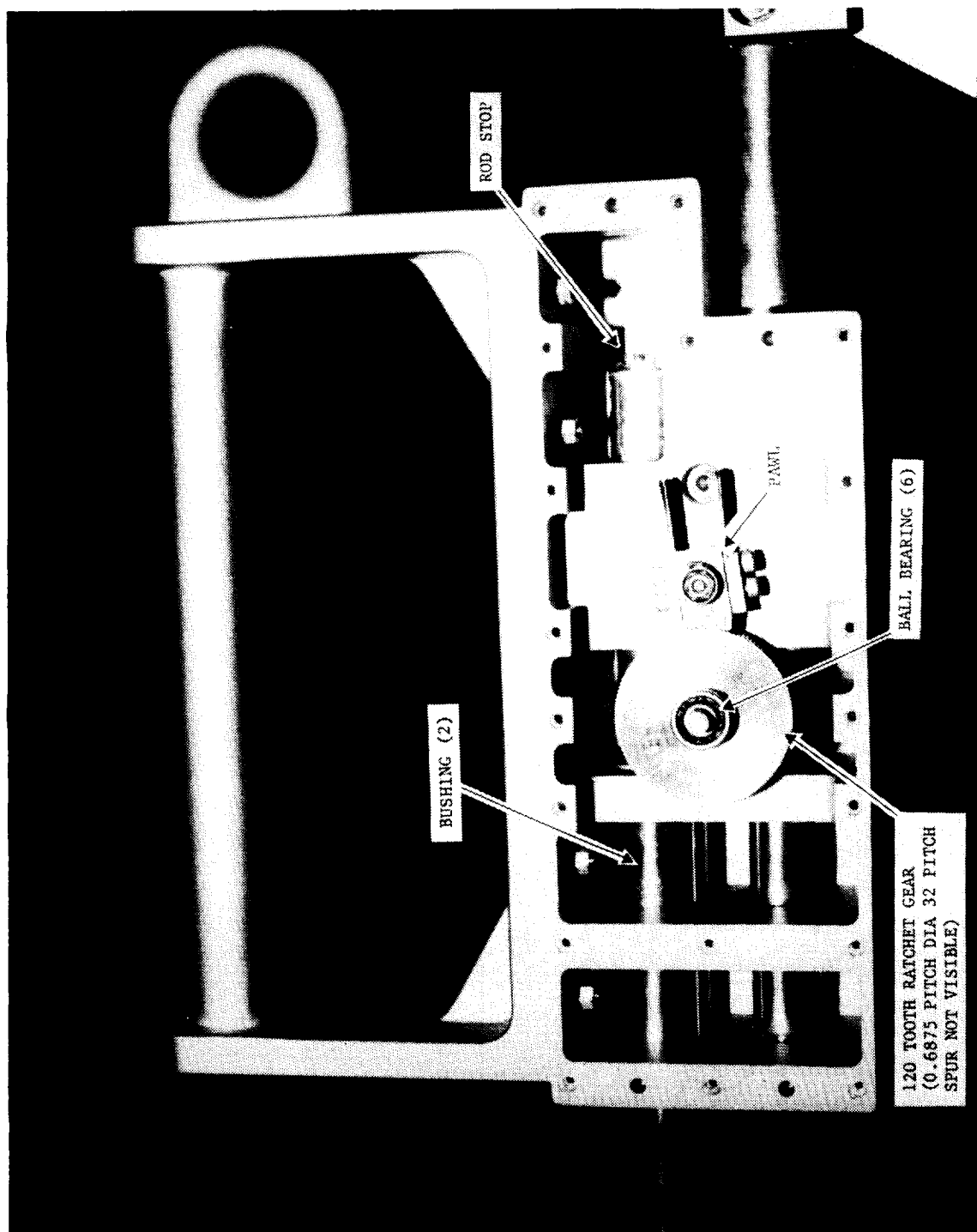


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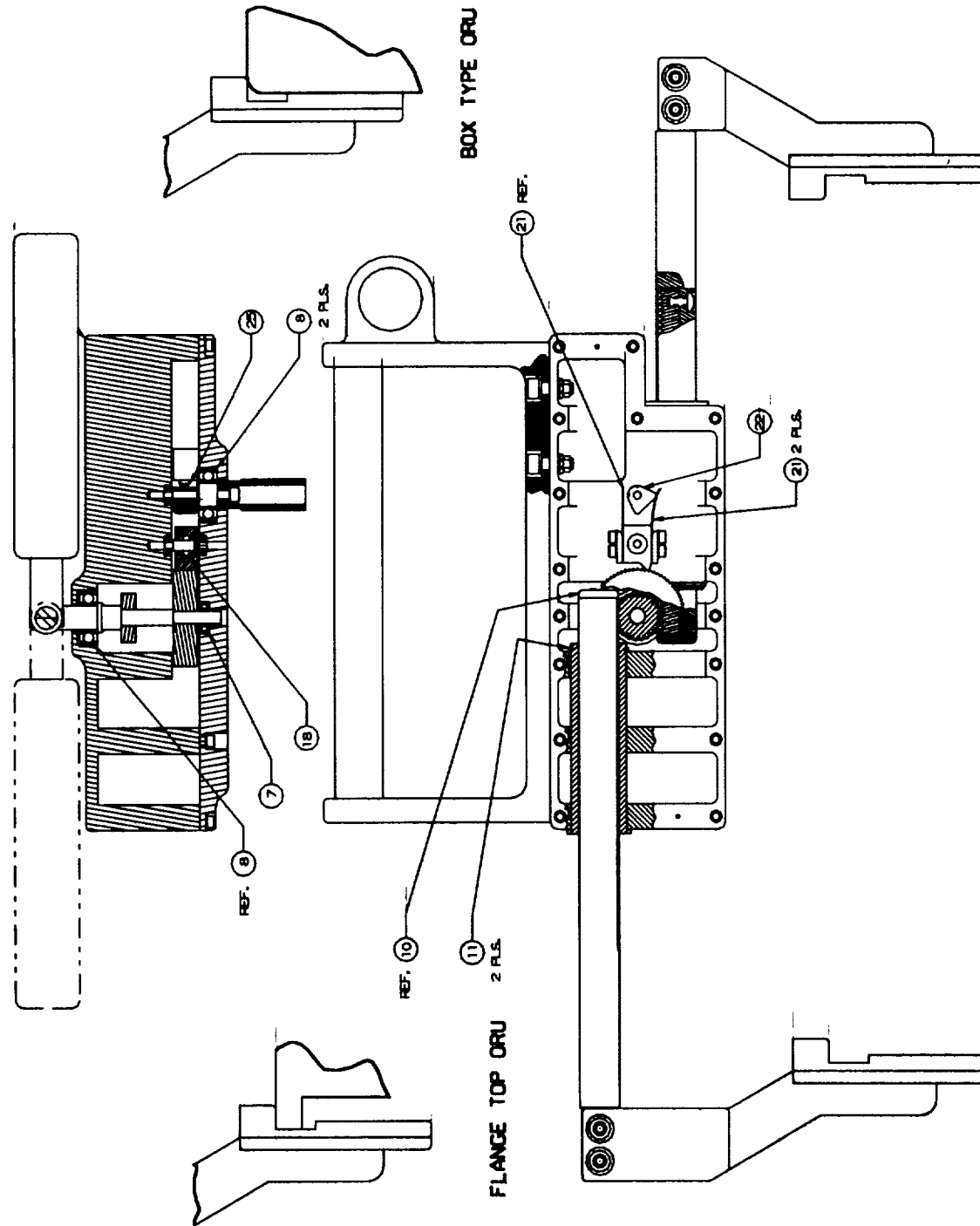


Figure 5. Internal Configuration

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Figure 6. Fit checks with early prototype handhold verified acceptability of envelope and mission suitability.  
Astronaut Bruce McCandless performs the test.

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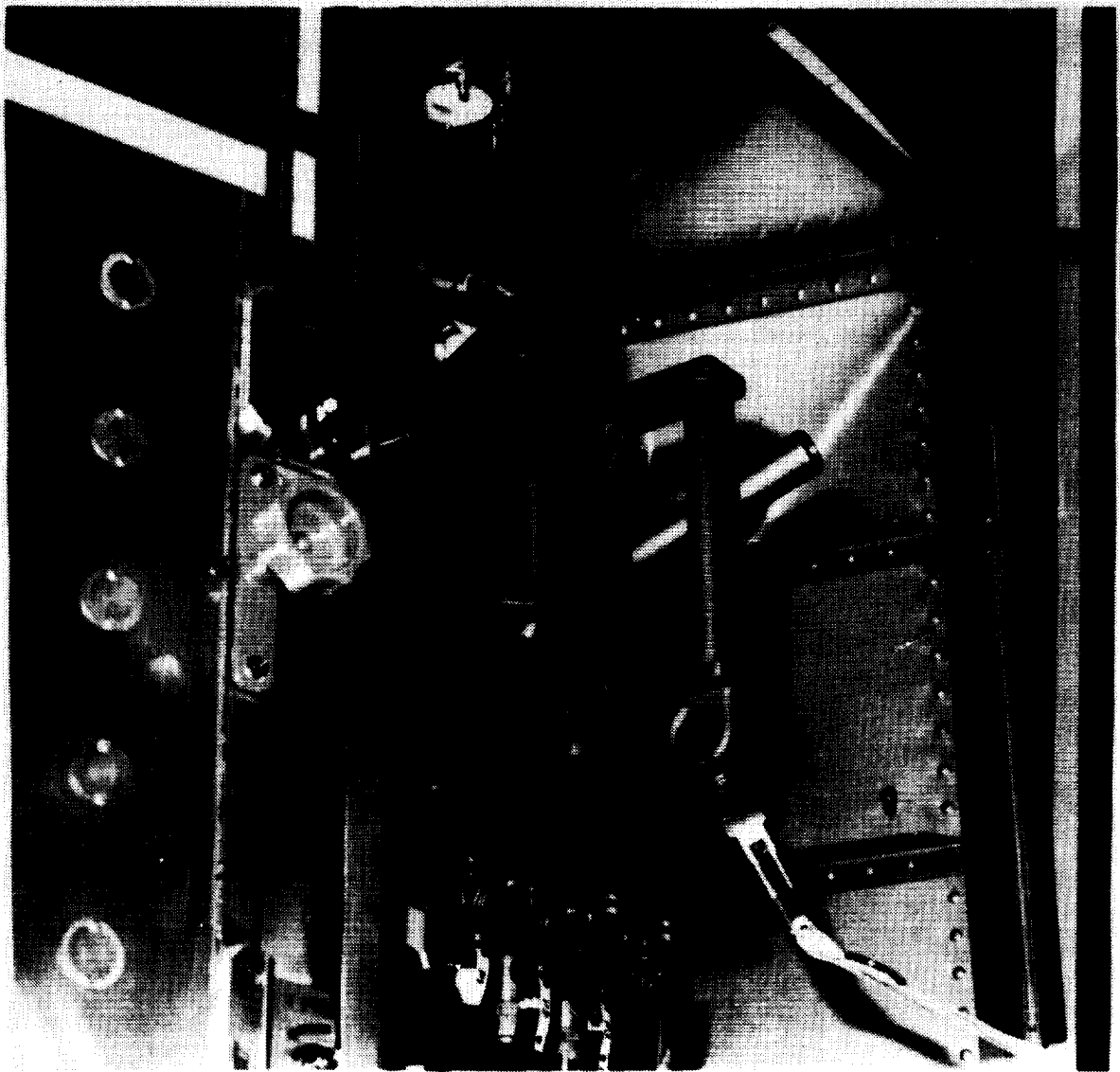


Figure 7. Later fit checks with flight fidelity unit verified latch and was useful in generating procedures and usage requirements.

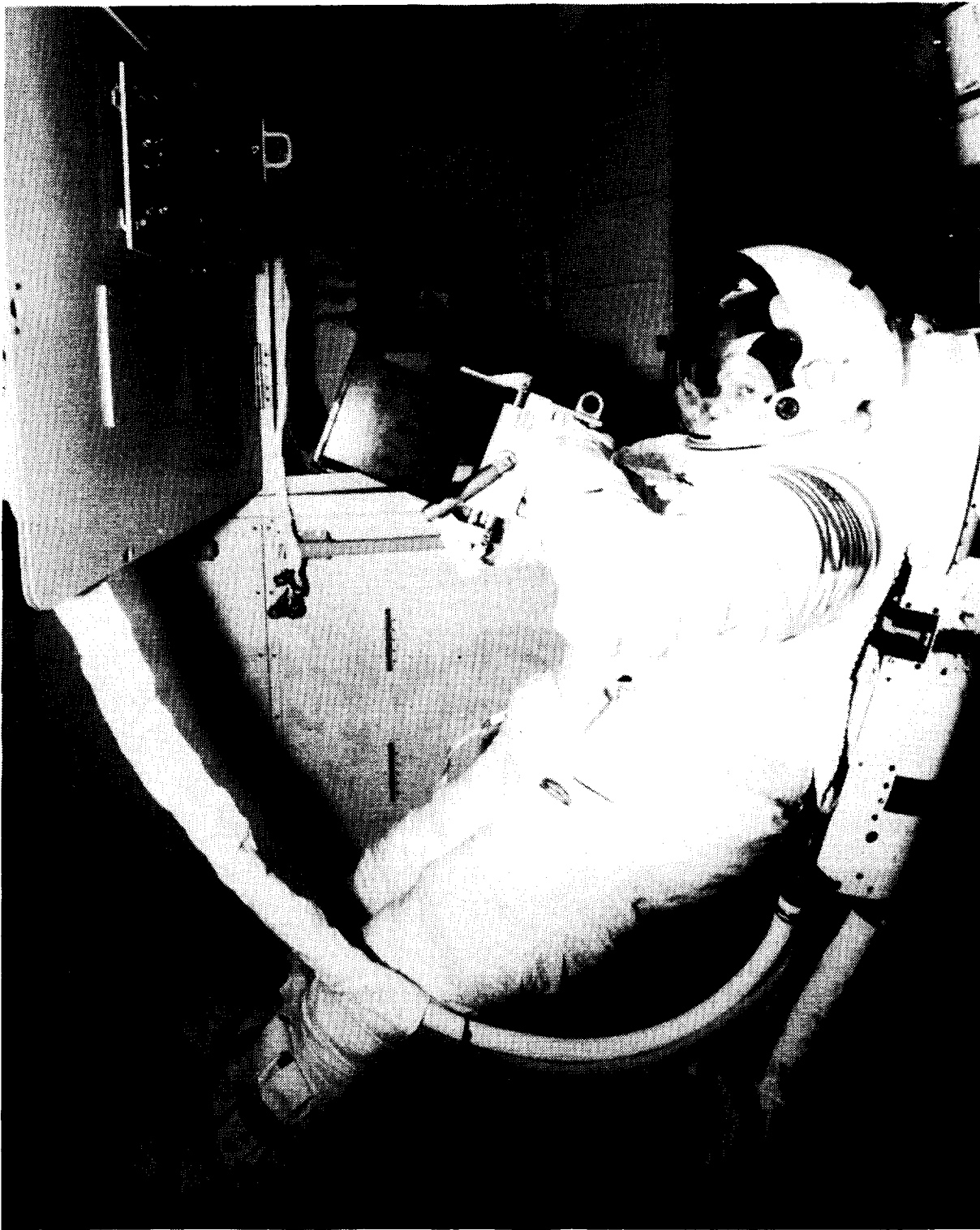


Figure 8. Neutral Buoyancy tests demonstrated usefulness of device for positioning ORU boxes.

